XIX. *An Experimental Inquiry into the influence of Nitrogen on the growth of Plants. By* ROBERT RIGG. *Communicated by the Rev.* J. B. READE, *M.A. F.R.S.*

ABOUT two years ago I had the honour of laying before the Royal Society an experimental inquiry into some of the chemical changes which occur during the germination of seeds and the decomposition of vegetable matter. On the present occasion I purpose to confine myself to an extensive series of experiments which have reference to the presence of nitrogen, earths, and salts in vegetable compounds, with a view of directing attention to the influence of nitrogen in the growth of vegetables.

As my inquiry is purely experimental, I may premise that I have had recourse to the well-known method of ultimate analysis, and the equivalent numbers which I employ are, carbon 6·12, hydrogen 1·0, oxygen 8·0, and nitrogen 14·0. That we may the more readily apply the proportionate quantity of nitrogen to our immediate purpose, I shall make one column in each analysis, which will represent by weight the quantity of nitrogen when compared with 1000 parts of carbon in the same compound. I also designate by the term *residual* those earthy and saline ingredients which are not decomposed during the analysis. In some of the experiments this residual may contain a little *foreign matter*, for in preparing the different compounds for analysis I seldom had recourse to any process of ablution, rather choosing to have a little foreign matter present, than to remove any part of that which was more particularly the object of research. That I might also examine the compounds as nearly as possible in their natural state, I very rarely exposed them to a higher temperature than 100° FAHR., inclosing them in very thin paper, and afterwards allowing them to acquire the hygrometric state of the atmosphere.

The first series of experiments to which I shall refer tends to show, that in that part of the seed where germination takes place nitrogen preponderates, when compared with its quantity in the other part of the seed. This result is derived from the analysis of the germ and cotyledons of beans, peas, barley, wheat, &c., a large excess of nitrogen being invariably indicated in the germ.

TABLE I.

	Carb.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
Germ of the garden bean	42·68	1·19	....	8·53	1·80	45·8	= 100	200
Cotyledons of the garden bean......	39·27	....	2·66	5·65	2·40	50·02	= 100	140
Germ of early garden peas	41·9	0·2	....	8·3	0·8	48·8	= 100	198
Cotyledons of early garden peas	40·1	....	6·5	4·2	1·3	47·9	= 100	104
Germinating ends of barley	39·6	0·2	....	1·9	0·6	57·7	= 100	48
The other parts of barley	39·2	....	....	1·0	0·8	59·0	= 100	25
Germinating ends of wheat	41·2	0·9	....	2·1	0·7	55·1	= 100	51
The other parts of wheat	40·6	0·3	....	1·6	0·8	56·7	= 100	39

Thus, for instance, it appears from the table of analysis, that the germ of beans and peas contain by weight about 200 parts of nitrogen for 1000 parts of carbon, while the cotyledons contain only from about 100 to 140 parts.

A second series of experiments disposes me to think, that those *seeds of the same kind* which contain the largest quantity of nitrogen germinate the earliest. Barley of the growth of 1835, containing 46 parts of nitrogen for 1000 of carbon, germinated in thirty-six hours after being taken out of the water in which it had been steeped; whereas barley of 1837, and containing only 35 parts of nitrogen, steeped in water at the same time, and kept under the same circumstances as the former, germinated in forty-eight hours. Similarly, I find that of the seeds, mustard, cress, rape, turnip, radish, and celery, those which contain the largest quantity of nitrogen and residual, germinate the earliest when kept under equal circumstances. It is necessary to state, that in these analyses the seeds were examined in the mass.

TABLE II.

	Carb.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
Barley of 1835	43·93	0·71	....	2·02	1·30	52·04	= 100	46
Barley of 1837	39·57	....	3·45	1·38	1·30	54·30	= 100	35
Mustard seed....................	50·74	2·36	....	3·55	3·90	39·45	= 100	70
Cress seed	46·8	1·5	....	3·3	4·8	43·6	= 100	71
Rape seed	55·3	3·4	....	2·7	3·1	35·5	= 100	50
Turnip seed	55·4	3·5	....	3·6	3·1	34·4	= 100	65
Radish	55·34	3·48	....	5·03	3·4	32·75	= 100	90
Celery........................	50·39	2·35	....	2·37	6·6	38·29	= 100	47

The chemical constitution of the *rootlets of seeds* before the *plumula* extends the whole length of the seeds, as in the instance of malted barley, differs from that of the malt, and also from the constitution of the barley in its original state. In these we have the rootlets containing a large quantity of nitrogen at a period when they will have to perform important offices in preparing the food for the young plant. That there is a similar difference between the chemical constitution of the roots and trunks of trees will abundantly appear from the annexed Table. And I may also add, that my experiments dispose me to infer that the quantity of nitrogen is largest in the spring, and diminishes with the season.

TABLE III.

	Carb.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
Barley in its original state..........	39·6	....	3·5	1·3	1·3	54·3	= 100	32
The malt made from the same	41·7	....	1·8	2·1	1·4	53·0	= 100	50
The rootlets of the malted barley....	40·5	0·4	....	4·3	3·5	51·3	= 100	106
Root of an apple-tree with the bark..	41·6	....	3·7	·7	1·2	52·8	= 100	16
Trunk of an apple-tree without the bark	42·8	....	4·8	·3	·3	51·8	= 100	7
Root of a plum-tree with the bark ..	42·4	0·4	....	·8	1·6	54·8	= 100	18
Trunk of the same without the bark..	42·8	....	....	·4	0·6	56·2	= 100	9
Root of cherry-tree with the bark ..	45·5	0·2	....	1·1	·8	52·4	= 100	18
Trunk of cherry-tree without the bark	43·9	....	4·3	·6	·2	51·0	= 100	10
Ash in a very dry state without the bark	46·6	....	....	0·5	·8	52·1	= 100	11
Ash root without the bark	35·2	0·8	....	2·6	9·4	52·0	= 100	74

Note.—The apple, plum, and cherry-trees were all of them very small; they had been in the ground several years, and had been rooted up because of their general unhealthiness. In a healthy state of the trees the nitrogen of the root is in a larger proportion.

But not only is the nitrogen more abundant in the roots of plants and trees; the residual also, when compared with the quantity in the trunks, will be found in excess in the roots.

Now if we admit the principle, that nitrogen is a powerful agent in favouring chemical action upon vegetable and animal matter, and that this residual is essential to the healthy performance of every function of the roots, as well as every other part of the plant, and forms, as it were, a most perfect skeleton of the whole; we have in these roots that which will favour such action in an eminent degree when compared with the other part of the tree.

It would be leading us into other subjects more extensive than the one now before us, if I were to go into, or treat upon, the chemical action which takes place by the agency of the roots, the compounds formed thereby, the heat produced by such action, the arrangement of the residual, &c. It will be sufficient, that in following up this part of the inquiry, we state as the result of experiment, that the *sap wood* is very differently constituted from the more perfect part, *the heart wood*, an excess of nitrogen being invariably found in the former.

TABLE IV.

	Carb.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
Young English oak sap wood	42·40	·18	....	·55	1·6	55·27	= 100	13
Heart wood of ditto	42·40	....	....	·16	0·7	56·74	= 100	4
Quebec oak sap wood	44·2	·14	....	·31	1·3	54·05	= 100	7
Heart wood of ditto	44·59	....	....	·13	0·6	54·68	= 100	3
English elm sap wood	41·20	·40	....	1·6	2·5	54·3	= 100	39
Heart wood of ditto	41·1	....	....	0·7	1·7	56·5	= 100	17
Acacia sap wood	43·79	....	2·49	·55	·50	52·67	= 100	13
Heart wood of ditto	41·36	....	6·67	·50	·20	51·27	= 100	12
Cedar from Africa sap wood........	42·06	·42	....	·39	2·8	54·33	= 100	10
Heart wood of ditto	39·92	....	....	·36	0·7	59·02	= 100	9
Chestnut sap wood	41·16	....	1·86	·38	·40	56·20	= 100	9
Heart wood of ditto	40·18	....	7·96	·29	·20	51·37	= 100	7

It will be unnecessary for me to say that the sap wood more readily passes into a state of decay than the heart wood. Here again the nitrogen and the residual being present in larger quantities in the former than in the latter, we have them exerting their influence as promoters of decomposition.

We have also the greatest quantities of nitrogen and residual in those timbers which grow the quickest: and further than this; for directly as the quantity of nitrogen and residual taken collectively, so do we appear to have the decay of timber, all other circumstances being equal. The following is the analysis of several kinds of timber which favour this inference.

TABLE V.

	Carb.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
Satin wood......................	47·20	....	....	·04	·50	52·26	= 100	1
Dantzic oak	44·90	....	....	·11	·50	54·49	= 100	2
English oak	43·20	....	....	·20	·60	56·00	= 100	4
Malabar teak....................	46·82	·48	....	·26	·18	52·26	= 100	5
Rangoon teak....................	47·93	·34	....	·43	·22	51·08	= 100	9
Spanish mahogany, fine-grained	49·0	....	....	·10	·50	50·4	= 100	2
Honduras mahogany, coarse-grained	40·97	....	....	·90	1·50	56·63	= 100	23
Lignum vitæ	51·22	1·21	....	·56	·60	46·41	= 100	11
Box.............................	46·4	·50	....	·50	·80	51·80	= 100	11
Rose wood......................	51·1	....	....	·60	2·50	45·8	= 100	12
Black ebony	42·4	....	....	1·50	5·0	51·1	= 100	35
American birch	45·0	....	....	2·2	1·5	51·3	= 100	40

Thus, for instance, the nitrogen in the satin wood may be considered almost inappreciable; and the same may be said of the residual in the Malabar teak, the nitrogen being also small in this timber. In Dantzic and English oak the quantity of nitrogen and residual are both very small. In American birch the nitrogen and residual are in large quantities, and, as is well known, this timber decays very quickly.

But it is not enough for us to find a difference in the proportionate quantity of nitrogen in the different parts of the same plant or tree; we must also observe that the quantity appears to be proportional to the functions which the parts of the plants have to perform in vegetation. For instance, if the agency of any part of the plant be great in the scale of vegetable physiology, so is the quantity of nitrogen, and *vice versâ*. So apparent is this, and so universal is the operation of this law over the whole sphere of inquiry in which I have been engaged, that we might almost consider this element, when coupled with the residual, to be the moving agent, acting under the influence of the living principle of the plant, and moulding into shape the other elements. We have this beautifully instanced in the chemical constitution of the different parts of wheat, barley, oats, common grass, turnips, cabbages, carrots, potatoes, &c., found by subjecting their various parts to analysis *at different periods of their growth* (See Table VI.). For by thus subjecting the different parts of the same plant to analysis at different periods of growth, we acquire much valuable information upon vegetation generally, and respecting the influence of nitrogen and residual in particular.

TABLE VI.

	Carbon.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
Flour of wheat not nearly ripe	41·2	1·8	....	2·9	2·0	52·1	100	70
Flour of the same kind nearly ripe ..	40·6	0·5	....	2·3	1·0	55·6	100	57
Leaves of the wheat not nearly ripe..	37·6	....	8·1	3·3	4·2	46·8	100	87
Leaves of the same when nearly ripe	38·4	....	....	2·1	4·6	54·9	100	55
Stems of the wheat not nearly ripe ..	39·8	0·8	....	3·5	4·0	51·9	100	87
Stems of the same when nearly ripe..	38·8	....	....	1·3	4·0	55·9	100	33
Chaff of wheat not nearly ripe	35·5	....	7·3	1·8	10·8	44·6	100	50
Chaff of the same when nearly ripe ..	31·2	....	1·7	1·3	11·0	54·8	100	42
Common grass not growing freely ..	41·1	....	3·1	4·4	5·5	45·9	100	107
Common grass gathered at the same time, growing very freely ...... }	39·5	1·6	....	5·6	6·5	46·8	100	141
Turnip when attacked by the fly	35·5	....	....	8·0	13·4	43·1	100	224
Cabbage leaf not eaten	39·5	....	4·8	8·1	5·9	41·7	100	203
The part eaten by insects	39·7	....	13·8	5·7	8·0	32·8	100	143
The insects themselves	36·0	1·3	....	6·3	14·0	42·4	100	175
Green part of another cabbage leaf ..	39·9	....	3·8	6·5	4·7	45·1	100	162
White part of the same............	39·2	0·8	....	8·0	4·9	47·1	100	205
Tendril of the same	38·8	2·7	....	5·4	6·3	46·8	100	138
Very centre part of the cabbage	33·0	1·7	....	4·1	4·0	57·2	100	124
Root of the same plant	39·2	1·4	....	5·5	4·5	49·4	100	141
Red clover stems	29·6	0·4	....	2·5	9·8	57·7	100	83
Leaf	28·6	....	7·7	4·2	5·0	54·5	100	145
Flower	30·4	....	10·2	3·6	5·0	50·8	100	119
Potato itself	37·1	1·4	....	2·9	3·4	55·2	100	79
Stem of the same	25·3	....	18·1	3·1	15·0	38·5	100	123
Leaves of the same	39·8	0·5	....	8·5	9·4	41·8	100	214
Apple of the same	32·9	....	16·4	3·9	5·6	41·2	100	117
Corolla of the same	38·8	....	8·5	3·3	4·4	45·0	100	85
Pistils of the same	36·2	2·2	....	4·6	9·6	47·4	100	129
Young carrot, ¼ of an inch in diameter	33·1	1·5	....	2·9	8·5	54·0	100	88
Leaves of the same	30·4	0·8	....	2·7	10·0	56·1	100	90
Stems of the same	28·7	....	2·8	1·7	11·2	55·6	100	59

There appear indeed to be various chemical actions taking place, in which these two elements are eminently concerned, viz. in the preparation of the food of the plants by the roots, and in combining this food with the other elements and fitting the whole to the various purposes of the plants.

Throughout the whole course of my experimental inquiry, I have not met with one instance wherein we have a large proportion of nitrogen and residual, that we have not violent chemical action and quick growth of the plants, all other circumstances being favourable.

By analysing *the leaves of trees* we may throw further light upon the operation of nitrogen. Of the almost numberless vegetables which cover the face of the earth, there are very few, if any, whose growth and produce afford us more information upon the chemical changes which occur during the growth of plants and the decomposition of vegetable matter than the vine. Its abundant flow of sap in the spring yields us a most important product for determining its food. Its foliage furnishes us with a plentiful supply of leaves for examination at different seasons : and by allow-

ing these leaves sometimes to remain on the trees until they are very abundant, and then removing a considerable portion thereof, leaving the rest to grow, we have at intervals of very few days an opportunity of chemically examining this very important and indispensable part of vegetable production under very different circumstances. By carefully dissecting these leaves, we are enabled to discover by analysis important changes produced in very few hours. From the proneness on the part of these leaves to pass into decomposition, at favourable temperatures, we have a feature brought before us which claims our best attention. And we have the fruit of this plant affording us, in its conversion into wine and other substances, an opportunity of examining into many important chemical changes, and I may add, of making the accuracy of many popular theories more than questionable.

The vines which more generally afforded me materials for examination are those which produce the white and black sweet-water grapes. They are in the open air, and are nailed to the south side of a brick wall. A series of experiments upon the leaves of these vines are given in Table VII., showing in a striking manner that nitrogen is in large quantities when they first make their appearance; that as they are developed, it decreases in proportionate quantity; that it is in excess during the period of their most rapid growth; and that towards the close of the year it is comparatively small.

TABLE VII.

	Carbon.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
The first small leaves on the white grape vine	37·7	0·5	....	5·1	9·5	47·2	= 100	134
Leaves from the same about a month afterwards	42·2	0·4	....	5·3	3·8	48·3	= 100	126
Leaves from the same in July	39·8	....	4·2	3·5	3·8	48·7	= 100	88
Leaves from the same in August	39·1	....	6·1	2·9	6·6	45·3	= 100	74
Leaves from the same in November ..	41·9	....	....	2·3	9·2	46·6	= 100	55
The first leaves on the black grape vine	41·8	1·4	....	7·8	10·3	38·7	= 100	185
Leaves from the same in June	42·8	....	3·8	5·4	3·8	44·2	= 100	126
Leaves from the same in July	41·5	....	1·1	3·6	3·0	50·8	= 100	88

With a view of ascertaining whether or not these peculiarities in the chemical constitution of the leaves of plants and trees were universal, I have had recourse to extensive analyses thereof, gathering the leaves from a great number of trees at different stages of their growth. The results hereby furnished may be obtained from the experiments in Table VIII.

TABLE VIII.

	Carbon.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
First small leaves from the lime tree in May	41·9	1·0	....	7·1	6·5	43·5	= 100	169
From the same in September 17	34·3	....	11·3	3·6	5·4	45·4	= 100	105
From the same in October 12	33·8	....	3·4	2·9	5·6	54·3	= 100	76
Acacia leaves, August 26, 1836	43·3	0·4	....	6·2	4·4	45·7	= 100	144
Acacia leaves, October 20, 1836	39·8	....	....	3·3	6·4	50·5	= 100	82
Almond leaves, August 26, 1836........	37·5	....	11·7	4·4	3·8	42·6	= 100	118
Almond leaves, September 27	37·0	....	....	3·8	4·0	55·2	= 100	102
Plane tree leaves, September 26, 1836....	41·4	....	18·7	2·7	4·4	32·8	= 100	65
Plane tree leaves, October 26	45·3	....	....	2·4	3·8	48·5	= 100	53
Red currant, May 3	40·1	....	2·0	6·2	3·5	48·2	= 100	155
Red currant, August 25	44·6	....	....	5·7	3·6	46·1	= 100	129
Very young ivy	40·4	1·6	....	3·6	4·6	49·8	= 100	90
Full grown ivy	41·6	0·4	....	3·2	5·2	49·6	= 100	78
Decaying ivy........................	42·4	....	....	2·2	5·8	49·6	= 100	52
Oak leaves, July 1836	40·8	0·6	....	4·3	3·9	50·4	= 100	104
Oak leaves, August	38·4	....	....	3·8	4·0	53·8	= 100	100

The analyses of the different parts of the flowers of plants are full of interest. The parts not only differ in chemical constitution with their state of developement, as appears in Table IX., in the instance of the rose, where the full-blown petals contained twenty-four parts of nitrogen, and the unexpanded and central petals contained sixty-six parts; but the various portions differ very materially from each other, and when taken in connexion with the germination of seeds, the growth of plants, their aliment, &c., throw much light upon the whole subject.

TABLE IX.

	Carbon.	Hydr.	Oxygen.	Nitr.	Resid.	Water.	Total.	Nitr. for 1000 Carb.
Full-blown rose petals	42·2	....	2·6	1·0	3·0	51·2	= 100	24
Rose petals not expanded, gathered at the same time, and from the same tree	45·2	1·1	....	3·0	2·5	48·2	= 100	66
Petals of the dahlia	35·5	....	10·2	2·7	4·0	47·6	= 100	77
Pistils of the same.................	34·8	1·3	....	4·2	4·3	55·4	= 100	120
Petals of the white lily	36·4	....	13·5	1·9	5·2	43·0	= 100	53
Pistils of the white lily	38·1	0·3	....	3·6	4·5	53·5	= 100	94
Pollen of the white lily	55·4	5·5	....	5·6	5·8	27·7	= 100	101
Stems of the anthers of white lily ..	40·5	....	....	2·2	5·0	52·3	= 100	55
Chrysanthemum, expanded petals....	39·2	....	....	2·1	3·7	55·0	= 100	54
Chrysanthemum, unexpanded	39·2	3·0	....	2·9	2·4	52·5	= 100	74
Pollen of the same.................	43·2	1·6	....	3·0	1·8	50·4	= 100	69
Leaves of the same.................	40·2	0·6	....	2·8	8·2	48·2	= 100	70
Leaves gathered June 16	41·4	....	4·1	5·0	4·2	45·3	= 100	121

Without adding to the number of experiments already furnished, I would observe, that I have not analysed any product in a natural state wherein I have not found both nitrogen and residual; and, of the great number that I have subjected to this

process, those which are embodied in this paper may be considered as approximating to an average of the whole, as regards both this gaseous element and the incombustible matter.

In conclusion, I would observe that the mode of analysis which I have adopted in the examination of organic compounds, so far as determining the quantity of carbon, hydrogen, oxygen, and residual are concerned, is the one described in the paper on vegetable decomposition to which I have already referred. Respecting the mode of determining the quantity of nitrogen, a very brief account of the plan which I have adopted is given in the Philosophical Magazine for January last; and by combining these two methods of ultimate analysis, I am enabled, in recapitulation, to detect very minute errors, and therefore to speak with certainty as to the accuracy and value of every experiment.